LESSON 24 – RANGING SCHEMES
(Application Exercise 3 due)
Time to learn some nomenclature for pulsed EM waves, examine the factors that determine a radar's maximum detection range and find out what determines range resolution.

Reading:
Stimson **Ch. 9, Ch. 10, Ch. 12 (exclude sections on ghosting)**
Problems/Questions:
Finish Application Exercise 3, Work on Problem Set 3
Objectives:
24-1 Be able to identify the different portions of a pulsed EM wave in the time domain.
24-2 Understand how noise and the power of the target's return effect maximum detection range.
24-3 Know what maximum unambiguous range is and what affects it.
24-4 Understand methods used to increase a radar's maximum unambiguous range.
24-5 Know how range resolution is determined and what factors enhance it.
24-6 Be able to determine a radar's resolution cell.

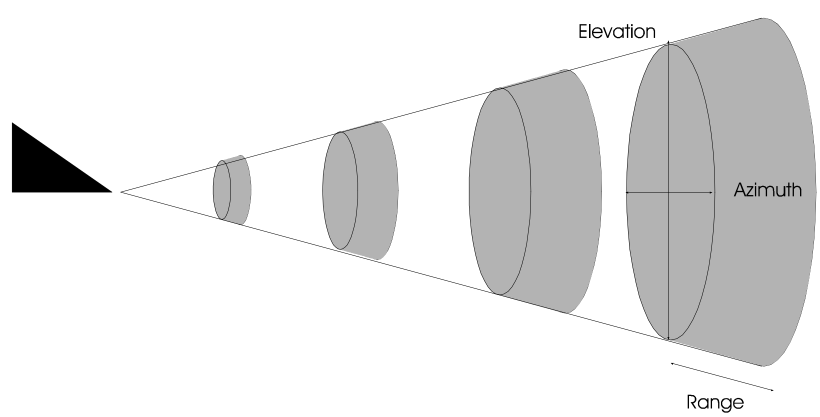
Last Time: Angular Resolution Lab

Today: Ranging Schemes
Resolution
Signal Strength/Noise
Ambiguities (PRF Jittering/PRF Switching)

Equations: $R_u = cT/2 = c/2PRF$; $n = \Delta R_{apparent}/\Delta R_u$ and $R_{true} = nR_u + R_{apparent}$

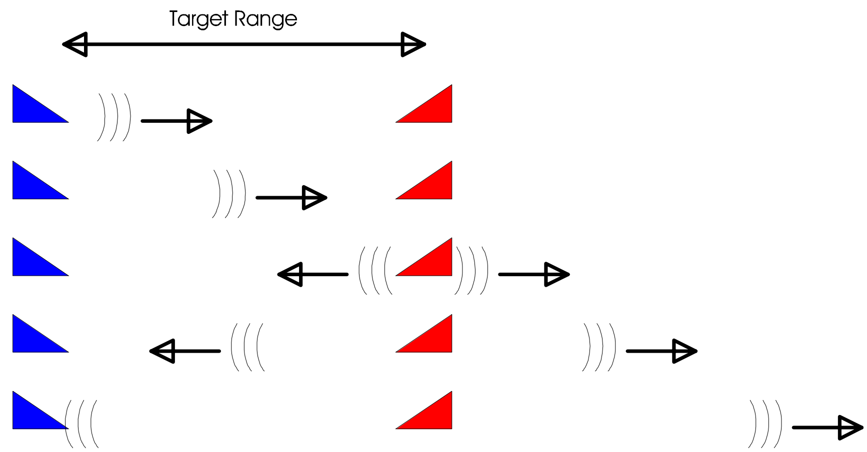
Rules of thumb for the F-4: frequency = 10 GHz (wavelength = 10 cm)
Dish Size = 1 m; Low PRF = 330 pulses per second (3,030,303 ns PRI) , 2000 ns pulse width => pulse takes up only about 1/1500th the time between pulses; High PRF = 1060 pulses per second (943,000 ns PRI), 400 ns pulse width => pulse takes up about 1/2400th the time between pulses)

Discuss how pulses look in space.



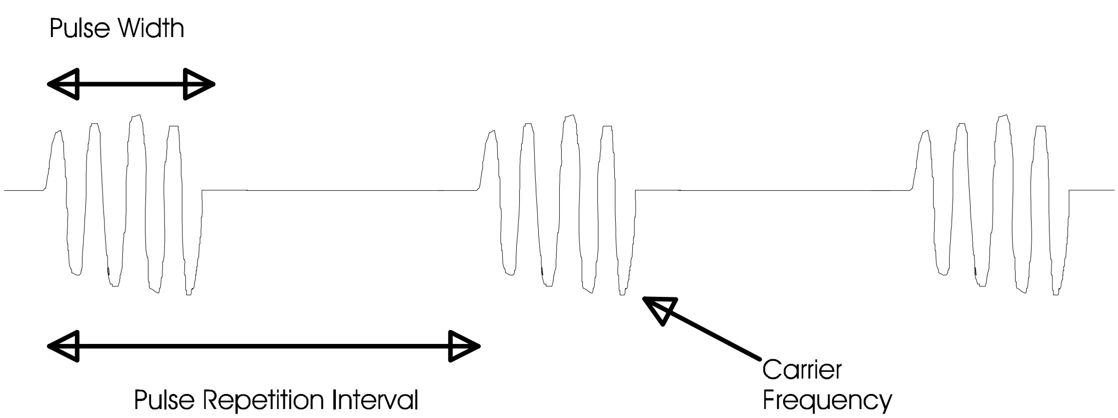
How do we determine at what range a target is located? We must pulse the radar and note the time the echoes return.

From kinematics, distance = velocity times time, so $d = c(t_{one\text{-}way}) = c(t_{round\text{-}trip})/2$ (note that the factor of two comes into play because of our timing of the round trip time for the radar pulse)



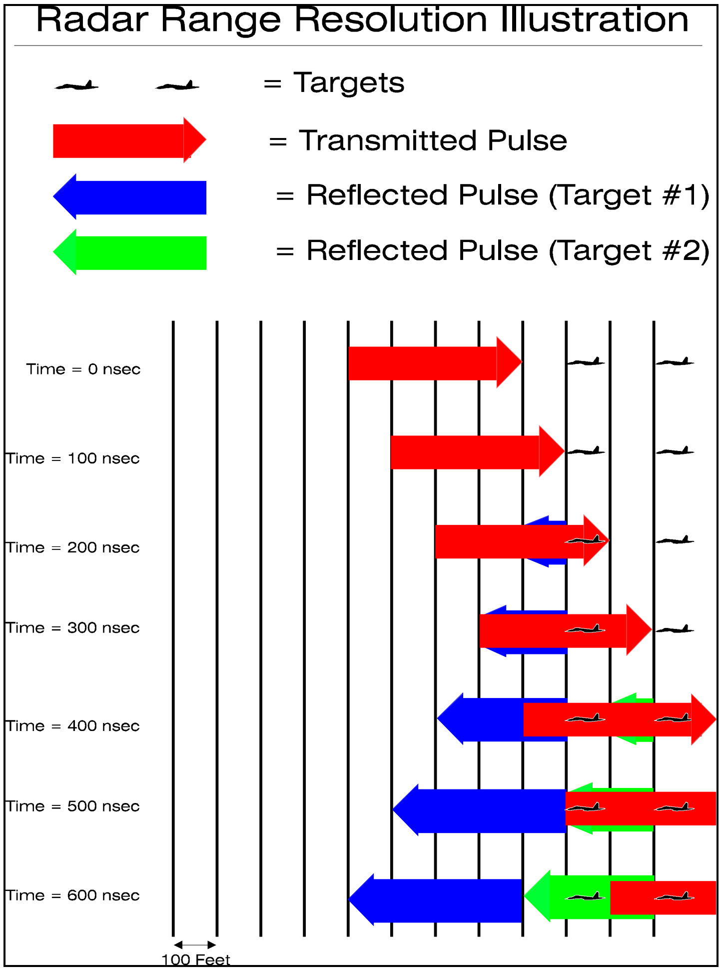
So pulsing the radar is a simple way to figure out what the range of the target is.

Let's look at pulses in more detail. There are four characteristics of any pulse: *carrier frequency*, *pulse width*, *frequency of repetition* of the pulses, and *intra-pulse modulation*. Today we'll discuss only the first three characteristics.



The F-4 in its best resolution mode has a pulse width of 400 ns. How wide is this pulse in space? What is the speed of light in ft/sec? Doing the conversion, it works out to just about 1 ft/ns. Thus, it's relatively easy to see that the pulse is 400 feet long.

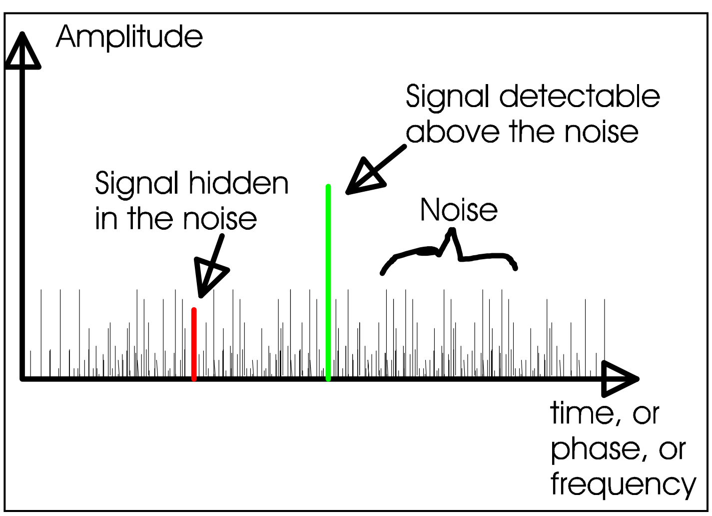
Range resolution (unprocessed) is exactly ½ the pulse width. Why? Show unresolved.avi and resolved.avi:



So, if two targets are separated in range by > L/2, they will show up as two targets to the interrogating radar. Otherwise, they're inside of the range res-cell

Which dimensions of the res-cell are the biggest?

What's better, long or short pulses? It's a tradeoff. A short pulse has better range resolution capabilities, but it carries with it very little energy, possibly too little energy to be detected by the interrogating radar when it returns.



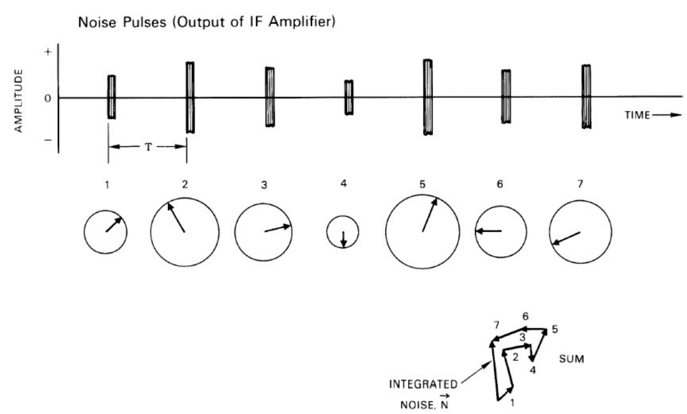
There's another engineering tradeoff—the pulses must be long enough to allow the receiver to detect them. Why can't receivers pick up low energy signals? NOISE. Noise is just randomly timed signals at random amplitudes and random frequencies and random phases.

How do we get around noise? For a pulse-Doppler radar, the most important randomness of noise is phase.

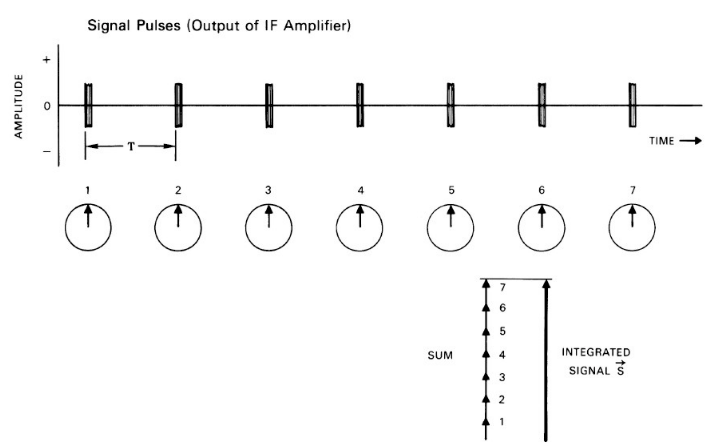
Get 7 cadets to write down an angle between 0 and 360. Get 7 other cadets to write down an integer between 0 and 10. Randomly combine the two lists to get 7 random phasors, which represent noise. Add these vectors on the board, and show that after a long time, the vector sum will be pretty close to zero.

Now, draw 7 short vectors with the same phase and amplitude. These non-randomly phased signals represent several low-energy signals emitted by the radar. Individually, each of them would be lost in the noise, but collectively, the radar's computer adds them all up and, voila, the signal appears out of the noise clutter.

Show overhead slide of Figure 10.29 and Figure 10.32 from Stimson for a further illustration.

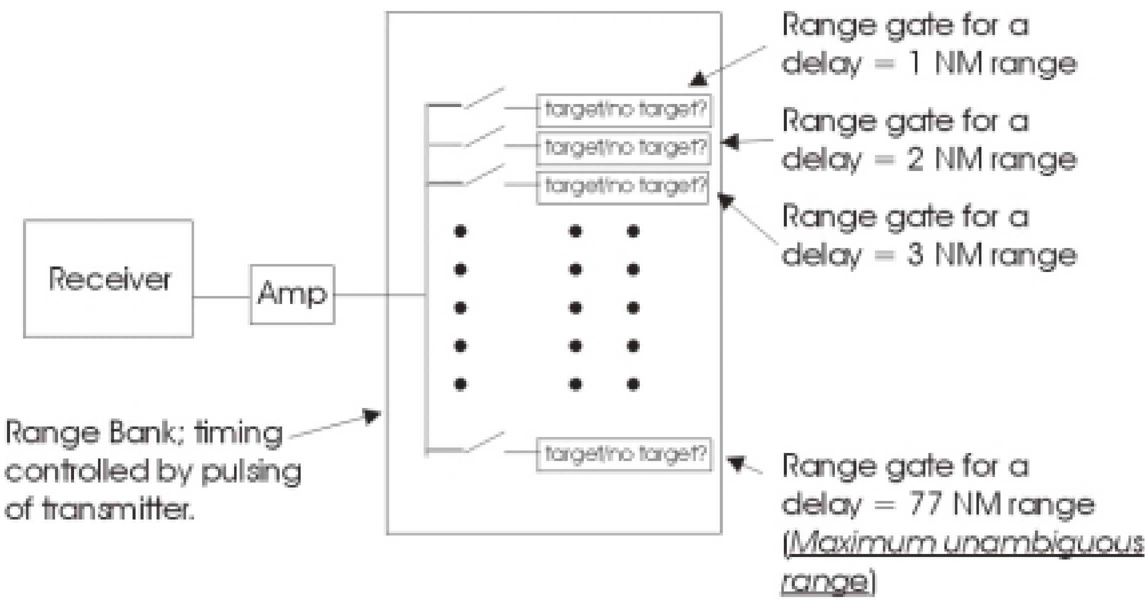


This says that you can use VERY short pulses (to get very good range resolution) and add the signals together, then subtract off an average noise value to get a bigger signal.



This implicitly forces us to discuss signals having constant phase, a subject we'll discuss later.

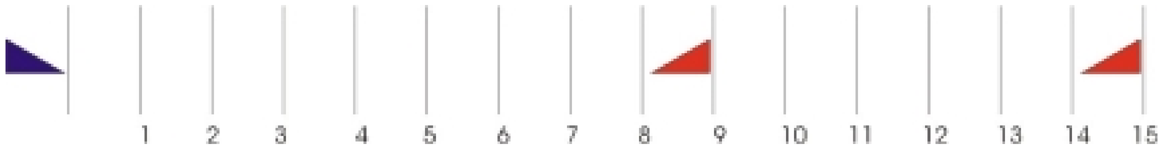
OK, so how do we know how far out a target really is? Remember, range = c ($t_{round\text{-}trip}$)/2. Let's look at the F-4 for an example. If the pulse repetition interval is 943,000 ns, how far apart are the pulses spaced in range? 943,000 ns tells us they are 943,000 feet apart, or 155 NM apart. Since the round trip distance is involved, we then divide by two to get range resolution figures, which says that our max unambiguous distance is 77 NM. Imagine we have two known targets, one at 10 NM and one at 87 NM. The way a digital radar times an echo is through the use of range gates, a set of switches that close in rapid succession. Let's say we have a range gate for every NM, that is, we will be able to know a target's range only to within the nearest NM. How long does each range gate stay open? 1 NM = 6000' = 6000 ns = 6 μs.



Anyway, our pulse travels out to our first target and returns, turning on the "target here" light in range bin #10.

But what about our target at 87 NM? If the pulse goes out at t = 0, the range bins cycle through "no target" all the way through the 77 NM bin, and then start cycling again with another pulse. 10 range gates later, the return from the long range target finally makes it back to the receiver. The radar receiver isn't able to tell the return from one pulse from another pulse, so it happily puts the target into range bin #10, even though it really is at a range of 87 NM. This is called range ambiguity, the problem where the radar can't tell whether the target is at 10 NM or at the max unambiguous range plus 10 NM.

Do an example with cadets as range bins and the following on the board. Assume the max unambiguous range for this example is 10 NM.



The maximum unambiguous range is found by $R_u = cT/2$, where c is the speed of light and T is the pulse repetition interval, or 1/prf.

Look at the same two targets, 10 NM and 87 NM. These targets are ambiguous with short pulse in the F-4. What if we switch to long pulse? What's R_u for long pulse? 1/prf = 1/330 pulses per second = .003 seconds per pulse, or 3 million nanoseconds, which equates to 3 million feet, or 250 NM.

Now, the two targets are no longer ambiguous! Do the example with the cadet range gates where the max unambiguous range is 7 NM.

So, what have we seen about range bins? If the target is displayed at its true range, it doesn't switch range bins when the PRF is changed slightly. If it is displayed at a range less than its true range, it will hop from bin to bin. Changing the PRF like this to resolve range ambiguities like this is called *PRF Jittering or PRF Switching*.

Jittering only eliminates targets that are beyond R_u. If they switch bins, they are never displayed to the pilot.

Switching takes into account how far the targets move in apparent range and uses this data to resolve the ambiguity, allowing targets at greater than the max unambiguous range to be displayed.

In either case, the display places all targets at their correct range.

Show and hand out copies of the transparency that describes how prf switching works. (file: this directory, "prf switching.xls")

$n = \Delta R_{apparent}/\Delta R_u$ and $R_{true} = nR_u + R_{apparent}$